Lateral Forces Study Guide:

Definitions:

General

Diaphragm - a structural system used to transfer lateral loads to shear walls or frames primarily through in-plane shear stress. Diaphragms are usually constructed of plywood or oriented strand board in timber construction; metal deck or composite metal deck in steel construction; or a concrete slab in concrete construction. It operates like wide flange beam on its side with the web being the diaphragm and the shear walls being the compression & tension flanges. The connections of the walls are critical to get the loads to the foundations.

Resonance - the state of a system in which an abnormally large vibration is produced in response to an external stimulus, occurring when the frequency of the stimulus is the same, or nearly the same, as the natural vibration frequency of the system.

Damping - is any effect, either deliberately engendered or inherent to a system, that tends to reduce the amplitude of oscillations of an oscillatory system.

Alluvium - soil or sediments deposited by a river or other running water. Alluvium is typically made up of a variety of materials, including fine particles of silt and clay and larger particles of sand and gravel.

Shale - a fine-grained sedimentary rock whose original constituents were clay minerals or mud.

Stress – force per unit of area.

Strain – the deformation of a physical body under stress.

Strength - in materials science, the strength of a material refers to the material's ability to resist an applied force.

Stiffness - is the resistance of an elastic body to deflection or deformation by an applied force. Opposite of ductility.

Stressed skin panel - is an insulated building panel that is comprised of a foam core sandwiched between two “skins.” The core, made from urethane or styrene foam, is both durable and light weight. The skins are most often made from oriented strand board (OSB), but other building material such as gypsum wall board, sheetrock, plywood, wafer board, and sheet metal are used as well. The exterior skin must be nail able material since the panels are attached to the building’s exterior enclosing the frame to create a thermal envelop.

Masonry hangers - A reinforcing bar support or hanger for use in a masonry block wall incorporates a pair of supporting arms for contacting the surface of a supporting block and includes vertically extending hanger members terminating in a rebar cradle for receiving and supporting a rebar to be positioned within the wall.

Seiche – a standing wave in an enclosed or partially enclosed body of water

Acceleration - in physics, any increase or decrease in speed is referred to as acceleration and similarly, motion in a circle at constant speed is also acceleration, since the direction component of the velocity is changing.

Maximum acceleration - occurs when period of the building is 0.5 seconds - which will result in 2-3 times the ground acceleration being experienced by the building.

Torsion - is the twisting of an object due to an applied torque. In circular sections, the resultant shearing stress is perpendicular to the radius.

P-Delta Effect - a phenomenon of combined vertical and horizontal stresses occurring when lateral loads (either seismic or wind related) cause horizontal deflection from the centroid and building mass in the resulting line of action crushes the column beneath.

Hertz – a unit of frequency measured in number of cycles per second (one Hz is one complete cycle back and forth per second).

Drift – horizontal deformation. The structural frame must be stiff to limit horizontal displacement when acted on by a lateral force.

Impact Load (Kinetic Load) - a dynamic short term impact that affects a structure. Examples are moving vehicles or elevator movement.

Deformation - a change in shape due to an applied force. This can be a result of tensile (pulling) forces, compressive (pushing) forces, shear, bending or torsion (twisting). Deformation is often described in terms of strain.

Abutment - to transmit the horizontal and vertical forces of superstructure to the foundations - usually a structure that supports an arch.

Parabolic - the shape of a hanging flexible chain or cable when supported at its ends and acted upon by a uniform load (for example, the deck of bridge).

Catenary - the shape of a hanging flexible chain or cable when supported at its ends and acted upon by a uniform gravitational force (its own weight)

Spandrel - is the space between two arches or between an arch and a rectangular enclosure.

Collector Element - a part of the structural system (like a bent, tie, or drag strut) that absorbs lateral forces and transfers them from horizontal to vertical members.

Bent – a component of the rigid frame system to resist lateral forces. It consists of a planar framework of beams and columns with moment resisting connections.

Drag Strut - a engineering term for a member that transfers lateral force from a vertical member to another member or element in the structural frame of a building. An example of a drag strut is a floor joist above a shear wall that is tied to the shear wall and extends across or along the floor diaphragm above. It is also called a collector or tie.

Link Beam - a beam (concrete, wood, or steel) that connects two different lateral elements such that they may act as one lateral element. For example, If there are two separate shear walls of different stiffness then a link beam may be used to connect the two walls. The overall system would be stiffer than the individual elements, and thus cause less deflection. It is the horizontal distance between any combination of vertical column, diagonal brace or shear wall.

Surcharge - any loading from above the soil line upon earth being supported by a retaining wall

Angle of Repose - also referred to as angle of friction - an engineering property of granular materials. The angle of repose is the maximum angle of a stable slope determined by friction, cohesion and the shapes of the particles.

Redundancy – a safety built into structural systems so if a main structural system fails, backup connections will work to prevent progressive collapse.

Grade beam - The part of a foundation system (usually in a building without a basement) which supports the exterior wall of the super-structure; commonly designed as a beam which bears directly on the column footings, or may be self-supporting, as a long strap footing.

Dog bone – a method used to strengthen a beam to column connection in a moment resisting frame by selectively reducing the top and bottom flanges (purposely weakening the beam) to make the connection itself stronger. Increases ductility.

Center of Mass - in a structure this is the centroid of all the structural and non-structural components.

Center of Rigidity - the centroid of only those members that participate in resisting lateral forces.

Shear Key – a short longitudinal stub of concrete below a footing used to prevent slippage and increase soil friction.

Form Tie - Any tie, in tension, which is used to prevent concrete forms from spreading as a result of fluid pressure of freshly placed, unhardened concrete.

Fascia - a term which generally describes any vertical surface which spans across the top of columns or across the top of a wall

Backup Bar - a strip of steel used to provide a solid base for beginning a structural steel weld.

Neutral Axis – the neutral axis is the line in a beam web located directly in the middle between points of tension and compression in which there are no stresses.

Box beams – a bending member of metal or plywood whose cross sectional area resembles a closed rectangular box

Diaphragm Shear - A diaphragm is a flat structural unit acting like a deep, thin beam. The term “diaphragm” is usually applied to roofs and floors. A shear wall, however, is a vertical, cantilevered diaphragm. These construction systems can be used when designing a building for lateral loads, such as those generated by wind or earthquakes.

Chord Forces – forces exerted by a principal member of a truss extending from end to end, usually one of a pair of such members, more or less parallel and connected by a web composed of various compression and tension members

Moment of Inertia - the rotational analog of mass. That is, it is the inertia of a rigid rotating body with respect to its rotation. The moment of inertia determines the relationship between angular momentum & angular velocity, torque and angular acceleration.

Area of the Section - a measure of the multiplication of the height x depth of a cross section.

Depth of the Section - the height of the section of a member. In steel beams, this is the web & thickness of flanges.

Section Modulus - the ratio in a beam of a cross section's second moment of area to its greatest distance from the neutral axis

Rigid Frame – two columns and a beam (or beams) attached to one another with moment connections; a moment-resisting building frame.

Coupling - any device used to connect two beams together at their ends for the purpose of transmitting load. There are two types – rigid and flexible. Rigid couplings are used when precise shaft alignment is required; flexible couplings are designed to transmit torque while permitting some radial and axial and angular misalignment

Creep – a permanent inelastic deformation in a material due to changes in the material caused by prolonged compressive forces.

Soft Story - generally refers to a first story whose stiffness is significant lower than that of the stories above; whose lateral stiffness is less than 70% of the stiffness of the story above.

Weak Story – a story where the overall strength is less than 80% of the story above.

Fixed Connection - a fixed connection between two members restrains all three degrees of freedom of the connected member with respect to one another. A fixed connection is sometimes called a rigid connection or moment-resisting connection. It restrains both rotation and translation.

Pinned Connection - can resist both vertical and horizontal forces but not a moment. They will allow the structural member to rotate, but not to translate in any direction. Many connections are assumed to be pinned connections even though they might resist a small amount of moment in reality. These are the typical connection found in almost all trusses.

Roller Connection - free to rotate and translate along the surface upon which the roller rests. The surface can be horizontal, vertical, or sloped at any angle. The resulting reaction force is always a single force that is perpendicular to, and away from, the surface. Roller supports are commonly located at one end of long bridges. This allows the bridge structure to expand and contract with temperature changes.

Parapet - a wall-like barrier at the edge of a roof or structure. It may serve to prevent unwanted falls over the edge or it may be a defensive, constructional or stylistic feature.

K-bracing - a type of braced frame with two diagonal supports representing a ‘K’. They are often associated with a link beam.

Seismic

Seismic retrofitting - is the modification of existing structures to make them more resistant to seismic activity, ground motion, or soil failure due to earthquakes. Other retrofit techniques are applicable to areas subject to tropical cyclones, tornadoes, and severe winds from thunderstorms.

Epicenter - the point on the Earth's surface that is directly above the focus where an earthquake or underground explosion originates

Hypocenter - refers to the site of an earthquake – the direct point miles beneath the earth’s surface.

Fault Line - a planar rock fracture which shows evidence of relative movement. Large faults within the Earth's crust are the result of differential or shear motion and active fault zones are the causal locations of most earthquakes. Earthquakes are caused by energy release during rapid slippage along a fault.

Strong Motion Accelerograph – an instrument that measures ground or building acceleration – provides this data during earthquakes.

Base Isolation – the separation of a building's foundation for direct rigid contact with the ground. This can be achieved through base isolators made of rubber and steel laminates and act as shock absorbers. This technique allows a building and the earth to move independently during an earthquake.

Vibration Isolators - spring & neoprene/fiberglass isolators used to reduce the transmission of noise, shock, and vibration produced by mechanical, industrial or process equipment & seismic activity into or within a building structure.

Tuned Mass Damper - also known as an active mass damper (AMD) or harmonic absorber - a device mounted in structures to prevent discomfort, damage or outright structural failure by vibration.

Cripple wall - a platform connected to a perimeter foundation through low stud-walls resting directly on a foundation.

Mud Sill - the lowest sill of a structure, placed on the foundation or directly on the ground.

Re-entrant Corner – an interior corner in a building found in 'L' and 'C' shaped plans which is particularly susceptible to lateral forces and torsion.

Liquefaction - describes the behavior of loose saturated unconsolidated soils, i.e. loose sands, which go from a solid state to have the consistency of a heavy liquid, or reach a liquefied state as a consequence of increasing water pressures, and thus decreasing effective stress.

Subsidence – The resulting aeration of the soil leads to the oxidation of its organic components, such as peat, and this decomposition process may cause significant voids If the roof of these voids becomes too weak, it can collapse.

Tectonic Uplift - a geological process most often caused by plate tectonics which increases elevation.

Pounding – occurs when two adjacent structures repeatedly bump into each other due to lateral seismic forces.

Wind

Chinook - a warm, dry wind that blows at intervals down the eastern slopes of the Rocky Mountains.

Santa Ana - a hot winter wind that blows toward the coast from the desert in Southern California.

Stagnation Pressure: direct wind pressure in lbs. per square foot on a vertical surface.

Basic Concepts:

Five Types of Building Irregularities:

- Torsion irregularity – result of asymmetrical plans on a discontinuity in the bracing system
- Re-entrant Corners – Plans in the following interior corner shapes - L T U C O +
- Diaphragm Discontinuity – either resulting from diaphragms with different degrees of stiffness or from having openings or cutouts
- Out-Of-Plane Offsets – lack of continuity in the lateral force resistance path
- Non-Parallel Systems – elements of the structural system are not in line or symmetrical with the major axis of the system.

Four Lateral Force Bracing Systems:

- Shear Wall – vertical walls and horizontal diaphragms
- Braced Frame – a frame that incorporates diagonal bracing members, tension wires, and struts to stabilize pinned connections.
- Moment Resisting Frame – a frame with fixed end connections. Moment forces transfer from one element to the next with redundancy.
- Dual System – a combination of a MRF with either Shear Walls or a Braced Frame

Three Types of Moment Resisting Frames:

- SMRF - Special Moment Resisting Frame

- IMRF - Intermediate Moment Resisting Frame
- OMRF – Ordinary Moment Resisting Frame
- MMRWF – Masonry Moment Resisting Wall Frame
- STMF – Special Truss Moment Frame

Types of retaining walls

- Gravity – uses its own weight to hold itself in place.
- Sheet Piling – made of fiberglass, steel or wood driven far into the ground.
- Cantilevered – (or heel) relatively thin stem wall attached to the retaining wall held by mass of soil.
- Anchored – uses cables or stays anchored back into soil or rock.
- Soil Nailing – technique where soil slopes are held in place by steel reinforcing bars.
- Mechanical Stabilization – MSE – soil constructed with artificial reinforcing by fixed layered mats.
- Counterfort Retaining Wall – a retaining wall built vertically with buttressed fin walls in tension.

Hierarchy of Building Structural Systems From Ductile to Rigid

- Moment Resisting Frames
- Braced Frames
- Shear Walls

A ductile system will absorb energy better but will suffer interior system stresses (ceiling tiles and grids and lights fall all over the place). Ductile systems absorb the energy better and result in less seismic force because they tend to be lighter than rigid systems. Ductile systems on bedrock work better than on clay.

A rigid system will not transfer energy as well to the member and is subject to draw more lateral force into the system which could result in failure.

Lateral Force Resistive Systems for tall buildings

- Bay Type System – Rigid frames in plan and elevation. Lateral loads are transferred out to the foundations at interior and exterior bays. Example = Home Insurance Building
- Tube System – Perimeter walls are rigid and rigidly connected at the corners. Lateral loads transferred at perimeter to the foundation. Example = Sears Tower
- Core System – Shear walls are placed inside the structure. Structure free plates are cantilevered from this core. Often used dually with a tube system. Example = 7 World Trade Center
- Suspension System – Floors are suspended from the structure and loads are transferred via massive compression piers. Example = Hong Kong & Shanghai Bank Building.

Rigid structure should be used on soft site (long period) and flexible structure on stiff soil (short period).

Recommended Seismic Design Practices

- Symmetry in systems
- Keeping the resistant design elements as far from the center of gravity/rotation for the building as possible
- Continuity in the building
- Redundancy in the design
- Torsion problems
- Avoid system irregularities.

Importance Factors (Earthquake)		I_E
Category I	Low hazard to human life [Storage facilities, Agricultural]	1.00
Category II	Other structures not listed	1.00
Category III	Substantial Hazard [Assembly Halls, Schools, Health, etc.]	1.25
Category IV	Essential facilities [Hospitals, Fire, rescue, Power Stations, Defense]	1.50

Construction sequencing:

- Installation of soil erosion and sediment control SE/SC measures
    - Selective vegetation removal for silt fence installation
    - Silt fence installation
    - Construction fencing around areas not to be disturbed
    - Stabilized construction entrance
- Tree removal where necessary (clear & grub)
- Construct sediment trapping devices (sediment traps, basins…)
- Construct detention facilities and outlet control structure with restrictor & temporary perforated riser
- Strip topsoil, stockpile topsoil and grade site
- Temporarily stabilize topsoil stockpiles (seed and silt fence around toe of slope)
- Install storm sewer, sanitary sewer, water and associated inlet & outlet protection
- Permanently stabilize detention basins with seed and erosion control blanket
- Temporarily stabilize all areas including lots that have reached temporary grade
- Install roadways
- Permanently stabilize all outlot areas
- Install structures and grade individual lots
- Permanently stabilize lots
- Remove all temporary SE/SC measures after the site is stabilized with vegetation

Retaining walls

- Know basic characteristics
- How different loads affect them
- Retaining wall surcharge. What does the force diagram look like? (Triangle that does not start at 0 on grade due to the surcharge)

Base shear

- How differences in soils, systems, irregularities, and zones affect the structure.
- Know how these variables relate to different resistant systems.

Ground Acceleration

- Periods of buildings versus soils/oscillation.
- How dampening devices affect resonance.

Period

- Similar to a sign or sound wave of how a building vibrates in reaction to a lateral force
- How stiffness relates to resonance
- Soils in long periods and short periods

Irregular & Regular Structures

- Irregular structures are characterized as having significant physical discontinuities in configuration of its structural system. They can be either part of the plan or the vertical systems & may require a dynamic structural system.
- Regular structures are devoid of the above.

Structural Irregularities

- How they respond to seismic activities, and wind forces. (FEMA & Ching)
- Brace system irregularities in detail and full understandings
- Plan shape irregularity

Building Characteristics of Long and Short Period Structures

- Think of a smooth placid pond with no waves or wind & the surface is like glass. Now, throw a pebble into the pond and notice how the water reacts. The waves emanate from the pebble (epicenter) - the largest closest to the epicenter, and dissipate out as they radiate away from it. Imagine this same idea on land where the ground acts the same as the water, except there are deposits of rock, clay, sand, etc. in various locations which will magnify or dissipate the waves to varying degree.
- Know how ground conditions, stiffness, strength, rigidity, ductility will affect the waves.

Design for seismic forces are generally considered to act horizontally in any & all directions. Vertical components of seismic forces are usually neglected.

Shear Wall

- Understand every detail you can find.
- Shear walls are stiffer but heavier
- Base shear force generally will be higher unless they are made of wood.
- Know how seismic loads are applied to shear wall

Parapets

- How do they react to seismic forces & overturning moments?
- Know base shear at the bottom of the parapets where they connect to the roof, etc.

Cost related to various systems in order of least to most expensive

- Wood
- Concrete
- Steel Frame

Torsion Diagrams - All buildings will experience torsion (called accidental torsion)to some degree - even due to someone moving a desk or file cabinet out of symmetry – the code wants this to be included.

The Gulf of Mexico is in seismic zone 0.

Method for determining Earthquake Resistance (IBC)

- Seismic Response History Procedure – mathematical model for the building is developed with software and subjected to ground shaking. Method is complex but always accepted.

- Modal Response Spectral Analysis – Distribution of seismic forces is based on deformed shapes of natural modes of vibration – determined by mass and stiffness of the building.

- Equivalent Force Analysis – Static horizontal forces are applied producing similar forces to those found in an earthquake. Used to design most buildings.

Method for Wind Analysis (IBC/ASCE 7)

- Method 1 – Simplified Procedure – wind pressures can be selected from a table with minimal calculations to the building. Primary use is for regular shaped low rise buildings.

- Method 2 – Analytical Procedure – wind pressures are determined using formulas tables, and figures provided by the code. Used to design many types of structures.

- Method 3 – Wind tunnel procedure – General guidelines for conducting wind tunnel tests. Expensive and primarily only used for irregular or tall buildings.

Site Exposure Categories

B – Urban/Suburban Areas, wooded areas, terrain with numerous low obstructions
C – Open terrain with scattered obstructions generally under 30 ft.
D – Flat unobstructed areas. Includes mud flats & slat flats.

Calculations:

There is no reference section in this test. You will have to memorize the formulas. Most candidates report they did not have to use any of the seismic or wind load formulas to solve any calculations - just basic F=P/A or M = $wL^2/8$ or V=wl/2. This however may not always be the case.

Calculate overturning moment; why it occurs and how to prevent

- One actual overturning moment question asking to figure the factor of safety- divide the D.L. resisting moment by the overturning moment.
- Questions showing overturning moment diagrams, simple conceptual questions.
- % of overturning resistance

Calculate the number of connectors (i.e. nails, straps) needed when they give you the weight each connector can handle and the pounds per linear foot that it needs to transfer.

Anchor bolt sizing - calculation on bolt size of column to footing connection - Choose from a size chart.

Calculate primary bending moments (Find the moment on a column of 3 story building due to a wind load)

Sign calculation - find moment at pole base.

Calculate force in diagonal member.

Calculate the bracing of wood frame

Chord Force calculation

Parapet Base Shear Calculations

Uplift Calculation

- some questions where a forces apply to not only one floor
- uplift on building parts
- only 90% of Dead load may be used to resist uplift

Direct Wind Pressure (Stagnation Pressure) $P=0.00256V^2$

Force needed to open a door - moment and shear formula.

Calculation - with center of rigidity and mass type

Calculate a period of oscillation

Calculate allowable stress

F = P/A

F = MA

Moment = $wL^2/8$

Base Shear Formula - V=ZICW/R

<u>Basic IBC Load Combination Calculations</u>

1.4D
1.2D + 1.6L + .5(L_r or R or S)
1.2D + 1.6L + .5(L_r or R or S) + f_1L or .8W
1.2D + 1.6W + f_1L + .5(L_r or R or S)
1.2D + 1.0E + f_1L + f_2S
0.9D + 1.0E or 1.6W

Reference:

Review GS/MM – I recommend Rich's Notes (on the forum ftp) / Archiflash.

Code references to wind and seismic forces

- Purpose - save/protect lives, levels of allowable damage relative to EQ intensity.
- UBC was referenced in most of the study materials, but we use the IBC and the terminology was different than UBC for similar variables. The test did not use the UBC terminology. Also glance through the BOCA code from 200
- Code on force ...railing etc....
- Know a variety of different load combinations according to code
- Seismic upgrade: I've been reading many sources to find what triggers seismic upgrade for an existing improvement, but can't get a clear cut answer. Concluded that each local building code have different requirement and the exam will probably present the case that if a candidate who possess a clear understanding behind code intention will be able to select the right choice.

FEMA Document 454 – primarily for information on retrofitting existing structures, visual identification of existing structures weaknesses, plan irregularities. The whole thing.

- How to retrofit an existing structure for lateral forces (historical structure, steel, wood, etc.)
- What system would you use? – Frames, moment resisting frames, braces, shear walls, buttresses.
- Ties used in retrofit and how they are used.
- Retrofitting- brick veneers, adding floors, etc.
- Know everything about retrofitting on roof & floor to wall connections.
- Know common ways to retrofit a building for earthquakes.

Applied Technology Council & the Structural Engineers Association of California (ATC/SEAOC) Training Materials on the Internet. ATC-48.

University of Buffalo - Earthquake Engineering & Structural Dynamics II

Wikipedia – great diagrams, animations, and text.

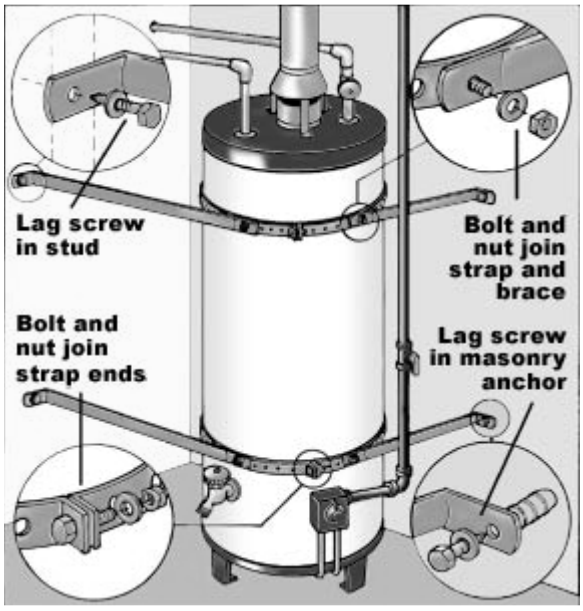
- Damping
- Resonance
- Soil Liquefaction
- Seismic Retrofit
- Retaining Wall

Kaplan
Ballast
Archiflash

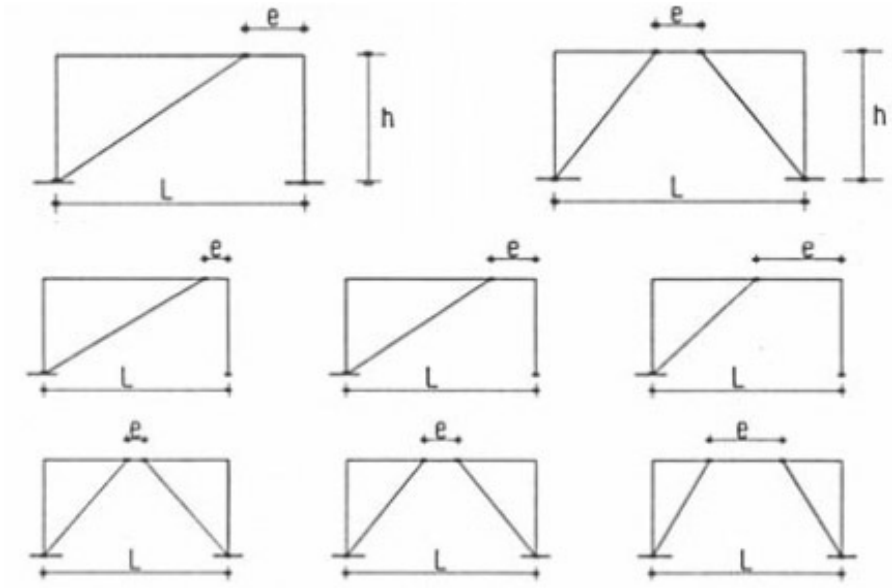
And of course, the single best piece of information – search 'ironwarrior' in the forum.

Diagrams:

Water heater or gas tank bracing - an overview of supporting water heaters in the San Francisco Bay Area. It's a two-stage set-up. First, you'll circle the heater tank with two strips of heavy-gauge perforated steel plumber's tape so you've got solid straps to attach braces to. You'll make the braces from thin wall conduit. Bolt one end of each brace to a strap, and attach the other end to a wall stud nearby.

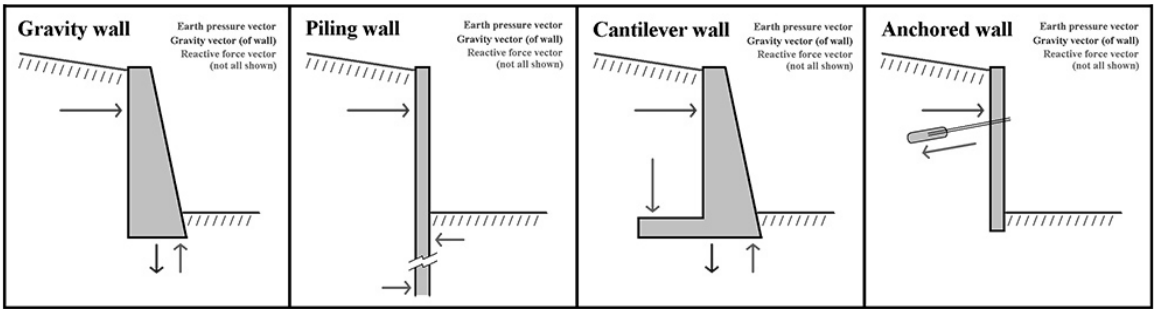


Link Beam – e is the eccentricity but could be a link beam

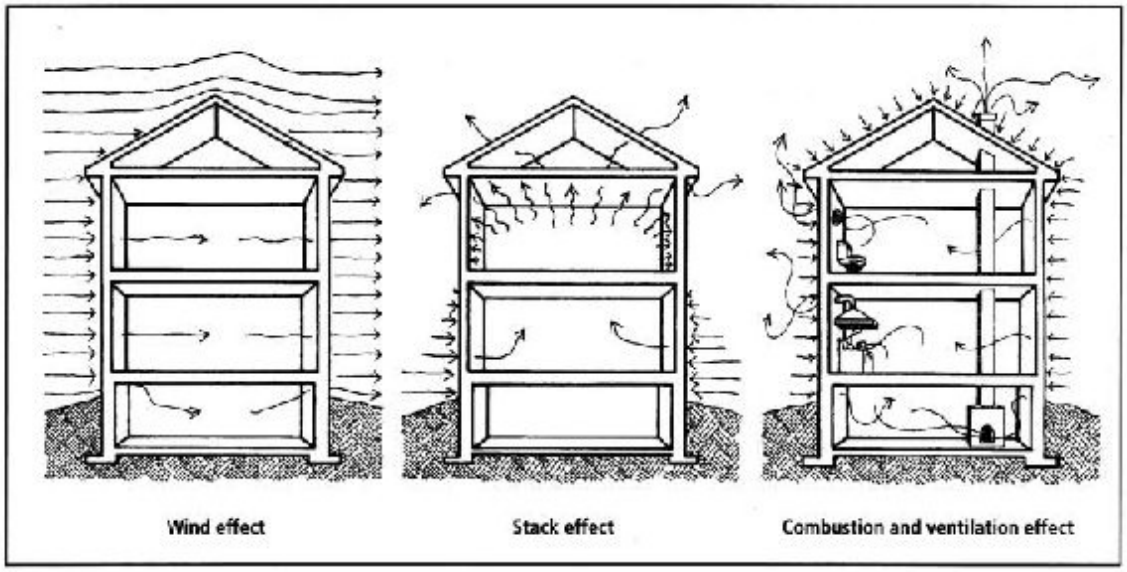


Lamella Roof

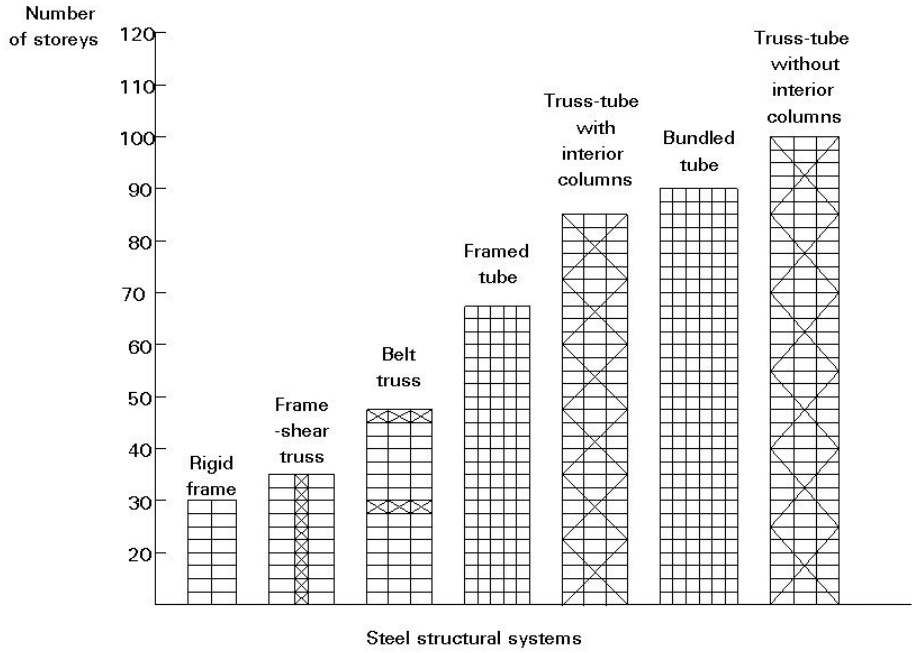
Retaining Wall



Various Wind Effects on a Home



Steel System Height Reference Guide



Steel Connections